Building Research Establishment Digest

CI/SfB 1976	DIGEST
81 (56.1)	253

September 1981

Heat pumps for domestic use

Whilst the UK sales of heat pumps are at present small, they are expected to grow steadily, especially in areas where natural gas is not available, in the next few years as their energy and cost-saving possibilities become widely known, and as the price of energy increases.

This digest explains some of the factors to be considered in a domestic heat pump installation, and points out some of the pitfalls, for the benefit of building designers, specifiers and users not previously acquainted with heat pumps. It is concerned primarily with pumps which use the outdoor ambient air as their heat source and which supply their output as hot water; however, most of the digest is also applicable to machines with warm-air output, and some of it to those with earth or water heat-sources.

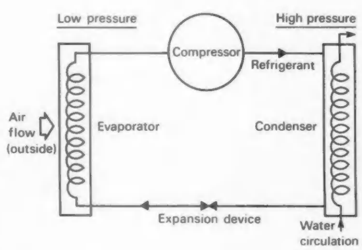

Fig 1 The most basic air-to-water heat pump circuit. Commercial machines may incorporate additional heat exchangers, refrigerant/lubricant reservoirs, control and safety devices etc.

Basic principles

The heat pumps at present commercially available for domestic use all operate on the compression cycle using electric drive. They extract energy from a low-temperature source using thermodynamic principles similar to those of a refrigerator except that the useful output is on the 'hot' side rather than the 'cold'. The main transfer of energy is provided by the latent heat of vaporisation and condensation of a refrigerant (usually Freon) which is pumped around a sealed circuit (Fig 1). It leaves the compressor as a hot vapour at high pressure and passes into the condenser through which is circulating the medium (air or water) from the heating system. The vapour, being at a higher temperature than the heating medium, gives up latent heat to it and in doing so condenses to a liquid. It then passes through a capillary or expansion valve, in which its pressure and temperature drop, into the evaporator, over which is flowing the energy source (eg the outside air). The refrigerant is now colder than the source and so there is a transfer of heat to the refrigerant causing it to vaporise. Now as a low pressure gas it is returned to the compressor for the cycle to begin again.

A refrigerant is chosen which will condense and evaporate at temperatures related to those of the heating medium return and the source.

The advantage of a heat pump is that the output energy available for heating is greater than the energy needed to drive it (the difference having been extracted from the source).

The ratio of output energy to drive power is known as the *Coefficient of Performance* (COP): defined as

$$\frac{\text{Total useful heat output}}{\text{Total electric power input}}$$

To estimate the performance and economics of a heat pump installation, the upper term should *exclude* any losses (eg from external pipework) and the lower one should *include* the power consumed by internal ancillaries such as circulating pumps and fans, crankcase heaters etc.

The COP varies as the source and output temperatures change: the smaller the difference between them, the higher the COP. Thus, to estimate the performance of a heat pump over a whole heating season, a *seasonal* COP is adopted. This can be calculated approximately from

Prepared at Building Research Station, Garston, Watford, WD2 7JR
Technical enquiries arising from this Digest should be directed to Building Research Advisory Service at the above address.

known heat pump performances and meteorological data, but is better taken from the monitored performance of an actual installation, as the effects of part-load cycling, which may tend to reduce the COP below its full-load steady-state values, are difficult to calculate. However, as a rough guide, the seasonal COP is unlikely to be less than the rated value at a source temperature of 0°C; figures of 2.0 to 2.5 are currently being realised.

Sizing and boosting

For new dwellings, heat loss calculations will probably be done by the designer; where a heat pump is fitted to an existing house, with or without an existing central heating system, similar calculations are necessary. As the cost per kilowatt of additional output of a heat pump is relatively high, it makes economic sense to base the calculations on as low-loss a house as can reasonably be achieved; so weatherstripping, reduction of unnecessary adventitious ventilation, radiator shields, improved wall and roof insulation where practicable, should all be assumed to have been done before the heat pump is installed.

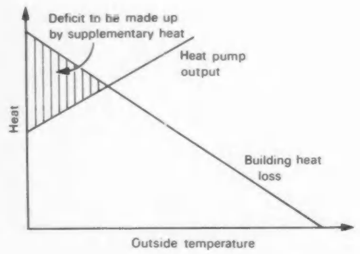

Fig 2 Variation of the space heating load of a building and the output of an outside air source heat pump as a function of temperature.

As outdoor temperature falls, the heat loss from a building (kept at a constant indoor temperature) rises, and the maximum available output from an air-source heat pump falls. The balance point is the outside temperature at which loss equals output plus adventitious gains (see Fig 2). By selection of a suitable size of heat pump, this is usually at air temperatures of 0°C to 5°C. At the higher balance points there will be a substantial auxiliary or 'boost' heat requirement on cold days. This could be met, for example, by leaving in place an existing boiler which would only be fired when the heat pump was unable to cope unaided, or by accepting that in such circumstances the living-room fire was lit, and its radiator turned off. Where the only boost envisaged is from direct electric-resistance heating, a lower balance-point is needed so that the effective coefficient of performance of the installation is not uneconomically low.

Alternatively a heat pump can itself be regarded as an auxiliary form of heating, capable of providing the full requirement during spring and autumn only. This is particularly so for water-source machines, which may be unable to operate in very frosty conditions.

The choice of tariff for an electrically-driven heat pump also needs consideration. If a dwelling is likely to be heated intermittently it may consume so large a proportion of its electricity at full rate that the 'off-peak' tariffs (which increase the full-rate price) may not be justified. On the other hand, particularly where substantial thermal storage can

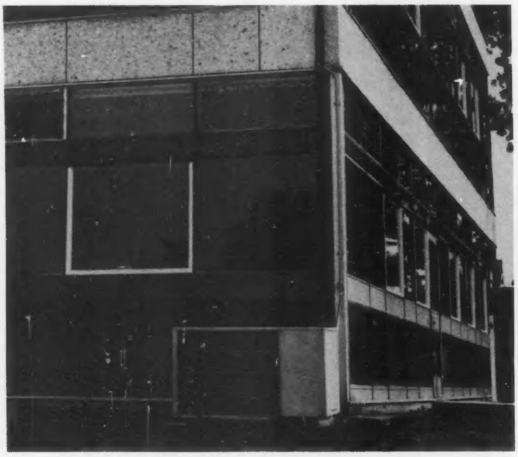

Fig 3 The outdoor unit of a 'split' heat pump.

be provided (eg heavyweight house construction and large hot-water cylinders) the tariffs with low off-peak should be chosen. Extensive thermal storage with off-peak topping up could provide the 'boost' heating in cold spells, but the economic implications of such systems are not yet clear. It must be remembered that 'off-peak' times also tend to be those of lowest air temperature, so the heat pump's performance will be somewhat reduced.

Output temperature

The hot water output of a heat pump is typically at 45-55°C, whereas for a domestic boiler it is at 65-75°C; some heat pumps incorporate a separate or 'superheat' circuit to provide part of the output at 60°C for domestic hot water.

Where a heat pump directly replaces a boiler, the lower temperature will mean a reduced heat output, at full load, from the existing radiators, perhaps by as much as one-half. However, this may not be a serious problem: existing heating systems almost always have their radiators oversized relative to the design heat loss of the rooms and, as discussed earlier, steps to reduce heat losses (below the original design values) should have had priority over the change to a heat pump. A careful check will, in most cases, show that the existing radiators (perhaps with increased flowrate or modified for top entry and bottom return) will still provide sufficient heating, although the ratio of convective to radiant output will have increased. Where it is clear that the existing unit would no longer be adequate, a change to a larger radiator or one with an extended heating-surface, or to a fan-convector, will be necessary. The radiant component of the heating will be reduced, and the occupants may notice this change close to the radiator; this in practice can sometimes lead to disappointment where the local radiant effect has been especially valued. In new buildings, low-temperature emitters can be used and heat pumps are particularly suited to underfloor heating systems because of the large effective surface areas.

If the heat pump is to be used in conjunction with a fossil-fuel boiler, the problems of reduced heat emission can be avoided. However, a heat pump cannot efficiently deliver heat much above 55°C and this may be too low for direct connection to boilers burning sulphur-laden fuels. The two appliances therefore become alternatives and valving arrangements should isolate the heat pump from the hot-water circuit when the boiler is operated.

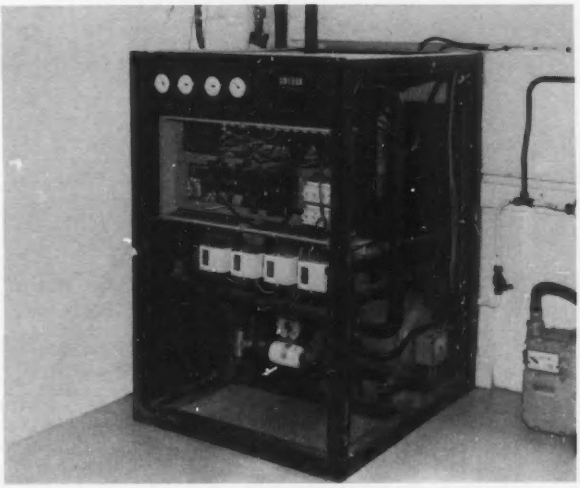

Fig 4 The indoor unit of a 'split' air-to-water heat pump, with its cover removed.

Split/unitary heat pumps

Air-source heat pumps have to pass substantial volumes (500m^3/kWh or more) of external air through their evaporators and so the evaporator housing is usually situated outdoors. The remainder of the heat pump can be installed either indoors or out. Indoors will mean a so called 'split' system, as there are two separate cased units which have to be joined by refrigerant piping as well as electrical wiring; the pipework necessarily has to be done on-site. The unitary machine houses all its components in a single outdoor casing, which must then be connected to the heating system of the house as well as to the electricity supply, and for convenience, an indoor control panel.

Each type of system therefore requires pipes, some of which will be hot, running from outdoor unit to house; obviously these pipes should be kept as short as possible and well insulated. In the case of unitary systems, it may be necessary to drain the pipes if the heating is to be turned off during freezing weather. In the case of the split system, the pipes carry refrigerant. Their installation requires the highest standards of care and cleanliness to ensure that no dirt, moisture or scale enters the refrigerant circuit. If it does it will eventually reach either the compressor or one of the valves (even if filters are fitted) or cause corrosion. It must be emphasised that the installation of such piping should only be done by persons properly trained in the correct techniques (such as dry-nitrogen purging during brazing) and lies beyond the craft training of a normal plumber.

Small unitary air-to-air heat pumps, requiring only a hole through a wall, and an electrical connection, may be suitable for DIY installation, but all other types need skilled plumbing and the attention of an expert to commission them.

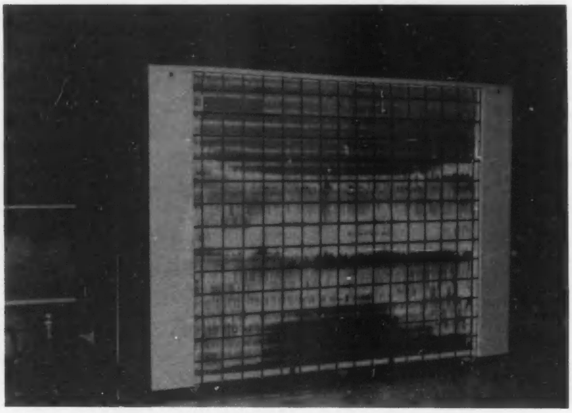

Fig 5 A unitary air-to-water heat pump (7.5 kW output) installed outdoors. Note the frost beginning to form on the evaporator fins (air temperature 6.5°C, 95 per cent RH)

Defrosting

The evaporator coils of an air-source heat pump have to be colder than the ambient air; this causes condensation on the fins. In certain climatic conditions, common in British winters, this condensate will freeze on the fins so that the evaporator gradually becomes coated with ice and its efficiency thereby reduced. Heat pumps therefore incorporate a defrosting system, which periodically removes the ice.

The user must understand the need for defrosting and to be aware (eg by inspecting the evaporator coils in cold, damp weather) of its efficacy. Malfunction of the defrosting arrangements is one of the commonest faults and inadequate defrosting can lead to ice blockage; less conspicuously, excessive or unnecessary defrosting is a waste of energy.

Siting of external unit

It has already been mentioned that the unit needs to be close to the dwelling to keep pipe runs short. The best location must be decided for each individual case, but the following points need to be borne in mind:

Air stream The evaporator fan will induce and expel a large volume of air, forming a very noticeable air current in its vicinity. The outgoing air will be some degrees cooler than ambient, and should not be discharged in a direction (eg across a side passageway) where people need to walk through it. Many machines discharge their air vertically to avoid this problem but they should not be installed below a window opening.

Weather and drifting Outdoor units are made with casings or special housings providing adequate protection against the weather although special precautions might be necessary near the sea. However, care needs to be taken to ensure that the air intake cannot be blocked by fallen leaves or driven snow. If this cannot be guaranteed, units must be sited so that any blockage can be quickly spotted and removed.

Condensate diposal Condensate from the evaporator has to be drained away and the casing usually incorporates channels to collect it and lead it to an outlet tube. Some machines have to be installed at a slight tilt to encourage the flow of condensate. Although the volume produced is not normally large, it is sufficient to require proper provision for its disposal. When frosting/defrosting cycles are occurring, the whole of the condensate for a cycle will be discharged in a short time (3-4 minutes) and the drain must be adequate to accept it. The possibility of this condensate itself freezing must also be considered.

Noise The noise made by evaporator fans and other outdoor components is, in the quietest machines, unobjectionable, but some can be annoying to a neighbouring house, particularly when bedroom windows are open. Acoustic screens can reduce evaporator fan noise by 5dB or so, but they are cumbersome and expensive and it is certainly best to site a heat pump in a position where any noise it does make is directed away from other dwellings. The compressor noise from a unitary machine is usually masked by the fan noise but in a split machine the compressor will be indoors, where it may emit as much noise as a large freezer. As with many mechanical devices, the noise levels can rise as the equipment ages so that an installation which is only just acceptable when new may become unacceptable after a year or two.

Solar assistance Some installations make use of extra benefits from solar energy, for example by drawing the evaporator air from the roof space, which will be heated by sunshine, or through some form of solar collector. In these installations, the type of assistance will determine the evaporator location.

Testing on start-up

Compared with boiler systems, heat pumps are more complex and their behaviour is much more closely related to outdoor atmospheric conditions. It is unlikely therefore that a single short running test will 'prove' all the functions of a heat pump, particularly if its installation is completed during the summer. It is possible in some cases to simulate a winter condition by partially blocking the air supply to the evaporator, and where a machine has a micro-electronic control a fairly complete diagnostic check can be made. Individual manufacturers have developed certain checking procedures appropriate to their machines.

However, it should be realised that only the experience of winter weather, with its varying combinations of temperature and humidity, can provide a full check on all aspects of a heat pump's performance, and an installer should be expected to carry out a return checking visit during the first spell of severe weather following a heat pump's installation. As this should include the observation of one or more complete defrosting cycles, it is unlikely to involve less than one full day, although two or more adjacent installations could be checked during the same period.

Fall-off

The performance of a heat pump can decline significantly due to the loss of refrigerant or a partial pipe or valve blockage (or simply to fouling of heat-exchanger surfaces) without any outward sign to the householder. This is especially so in installations where electric-resistance 'boost' is automatically called in by the thermostatic controls: the next electricity bill may be the first indication that something is amiss. It is important, therefore, that the householder should have some means of judging whether the heat pump's performance is up to standard. A simple temperature difference check may be sufficient, or machines with micro-electronic controls can be programmed to perform their own regular checks, and show a warning light if a fault develops.

Economics

It is not at present possible to make general statements about the economics of domestic heat pumps, except that it would be unusual to find circumstances in which an electrically-driven heat pump was competitive with a gas-fired boiler at 1981 gas and electricity prices. The running cost of such a heat pump is already lower than that of oil-fired and direct electric systems but the high capital cost of the installation means that economic calculations are necessary which allow for the different importance of capital and operating costs to different users.

To obtain a comparative assessment for a particular installation, the following data are necessary:

House	Design heat loss Seasonal total heat loss Annual hot water consumption (if supplied by the heat pump)
Heat Pump	Capital cost Installation cost Expected life Expected maintenance cost Expected seasonal COP Electricity tariffs
Oil Fired Boiler	Capital cost Installation cost Expected life Expected mainentance cost Expected thermal efficiency (or take as 65-70 per cent) Oil cost
Off-peak electric storage heating	Capital cost Installation cost Electricity tariffs *It is conventionally assumed that, of the heat emitted by storage heaters (in total, 100 per cent of electricity consumed) only 75 per cent supplies heat usefully available when it is needed.*

Fig 6 Indoor and outdoor views of a 2 kW air-to-air heat pump designed for single-room heating and installed in a trial house.

Specification

A prospective purchaser of a heat pump will need, and can reasonably expect, the following information:

Performance

Output in kW, at air temperatures of about 0°C and 6°C.

Output at −6°C and 15°C will also be useful as the extremes under which the machine might run. (Some heat pumps can be overloaded at high outdoor temperatures and may include a cut-out to prevent this).

The output may additionally be quoted at different heating system flow temperatures (say 40°C and 60°C). An estimate of the *seasonal* coefficient of performance during a typical UK heating season:

$$\frac{\text{Total useful heat output}}{\text{Total electric power input}}$$

Consumption

Power consumed in kW (including fan and pump power) under the running conditions above. Nature of supply (phase, hertz, volts) and maximum starting current. Size of isolator and supply cable required.

Source

Approximate volume of air handled through evaporator. Fan rating (kW). Cross-sectional area of air inlet/outlet (if relevant). Pipe sizes for earth or water sources.

Output

Temperature of hot water and central-heating supplies (if separate). Connecting pipe sizes. Designed flow rates and pressure drops. Circulating pump rating. For air-output machines, air flow, temperature, and duct sizes.

Control

Control arrangements for heat pump. Other controls, eg room thermostats, outdoor temperature sensor, thermostatic radiator valves (these may not necessarily be the same controls as supplied for boiler fed systems).

Boost

Rating of electric-resistance boosters if fitted, and type of control. Other boosters, or control interfacing into existing (eg boiler) system.

Size Indoor and outdoor units. Weight, with and without packaging.

Installation Diagrams showing positions of connections, access covers, controls etc, with any recommendations to facilitate maintenance access. Maximum and recommended interconnecting pipe lengths for split systems. Diagram of weather cover (if separate). Details of condensate discharge piping.

Noise At various distances (up to 20m) and directions for outdoor units; at 1m for indoor units.

Refrigerant Type and standard charge weight.

Defrosting Means of defrosting and of controlling defrost cycles. Arrangements, if any, for calling-in boost heaters during defrosting.

Price Making clear any additional costs and including a rough estimate of typical installation cost, and of optional accessories.

Installer Explanation of whether manufacturer undertakes installation or lists and trains approved installers.

Warranty A clear statement of what warranty is provided over and above the purchaser's legal rights, and the apportionment of liability between manufacturer, seller and installer.

Maintenance An indication of how much annual maintenance might reasonably be expected.

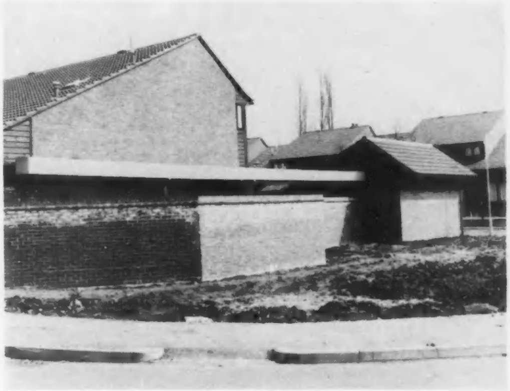

Fig 7 A communal heat pump. The small building on the right houses an air-to-water heat pump, design output 70 kW, to heat a row of 12 houses. The horizontal duct carries the water flow and return mains.

Further reading *which includes some discussion of further types of heat pump now under development*

FREUND, P; LEACH, S J; & SEYMOUR-WALKER, K J. Heat Pumps for use in Buildings. BRE Current Paper 19/76.
FREUND, P. The Application of Heat Pumps in Buildings in the UK. Proc CIBS Symposium on Energy, Services & Buildings, 1980.
HEAP, R D. Heat Pumps. E & FN Spon, 1979.
REAY, D A & MACMICHAEL, D B A. Heat Pumps, Design and Applications. Pergamon Press, 1979.
Energy Conservation: a study of energy consumption in buildings and possible means of saving energy in housing. BRE Current Paper 56/75.
Energy consumption and conservation in buildings. BRE Digest 191.

Department of the Environment Building Research Establishment

Dmd. 699220 ISBN 0 11 725086 4